

Review

# Research Progress and Development Trends in Smart Hospital Operations Management under Digital Transformation

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**Abstract:** Digital transformation is changing hospital management from fragmented information processing toward integrated, data-driven, and increasingly intelligent operations. Smart hospitals combine electronic health records (EHRs), interoperable data platforms, artificial intelligence (AI), the Internet of Medical Things (IoMT), cloud computing, automation, real-time dashboards, and emerging digital twin technologies to support clinical services and organizational management. This narrative review synthesizes recent research on the progress, management value, implementation barriers, and development trends of smart hospital operations. Current applications are concentrated in patient flow and bed management, operating-room scheduling, workforce and equipment allocation, medication and supply-chain management, quality and safety monitoring, and administrative automation. Evidence suggests that digital technologies can improve information visibility, forecasting, coordination, and process standardization; however, technology deployment alone does not guarantee better outcomes. Benefits depend heavily on interoperability, data quality, workflow redesign, organizational leadership, user acceptance, cybersecurity, governance, and continuous performance evaluation. In particular, poorly designed EHR workflows may increase documentation burden, while AI systems introduce risks related to bias, transparency, accountability, and lifecycle monitoring. Future smart hospitals are likely to evolve toward integrated command platforms, multimodal AI, ambient intelligence, predictive and prescriptive analytics, and digital twins capable of simulating operational scenarios before real-world implementation. From a medical management perspective, the central task is therefore to shift from technology-centered construction to value-oriented digital governance. Hospitals should align digital investment with measurable operational objectives, establish multidisciplinary governance mechanisms, and evaluate efficiency, quality, safety, workforce experience, equity, and return on investment simultaneously.

**Keywords:** smart hospital; digital transformation; hospital operations management; artificial intelligence; electronic health record; healthcare management

Received: 12 August 2026

Revised: 01 October 2026

Accepted: 16 October 2026

Published: 22 October 2026



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## 1. Introduction

Hospitals are complex service organizations in which clinical care, logistics, finance, human resources, equipment, information systems, and patient experience must be coordinated in real time. Population ageing, increasing prevalence of chronic disease, shortages of healthcare workers, rising costs, and higher expectations for safety and convenience have intensified pressure on hospital managers. In this context, digital transformation is no longer limited to replacing paper records with electronic systems. It increasingly involves redesigning organizational processes around data, connectivity, automation, and intelligent decision support. The World Health Organization (WHO) has emphasized that sustainable digital health requires the coordinated development of technological, financial, organizational, and human resources rather than isolated digital projects [1].

The concept of the smart hospital reflects this broader transformation. A smart hospital can be understood as an institution that integrates clinical, operational, and administrative information through interoperable digital infrastructure and uses real-time data and intelligent technologies to improve care delivery and organizational performance [2]. Compared with conventional hospital informatization, the smart-hospital model emphasizes continuous data exchange, process awareness, predictive analysis, human-machine collaboration, and the capacity to learn from operational data. Recent literature identifies EHRs, AI, IoMT, cloud platforms, automation, robotics, mobile technologies, and digital twins as key technological components [2,3].

For medical management, the relevance of smart hospitals lies not in the novelty of individual technologies but in their ability to improve the allocation and coordination of limited resources. A digital system creates management value only when it helps hospitals reduce avoidable waiting, match capacity with demand, improve staff productivity, detect risks earlier, standardize processes, and support accountable decision-making. This review therefore focuses on smart hospital operations management rather than on diagnostic AI alone. It summarizes major enabling technologies, current operational applications, management value, implementation barriers, and emerging trends, and proposes practical implications for hospital managers.

## **2. From Hospital Informatization to Smart Operations**

Hospital digitalization has developed through several overlapping stages. The first stage focused on basic informatization, including hospital information systems, laboratory and imaging systems, billing systems, computerized physician order entry, and EHRs. These systems improved record availability and reduced dependence on paper, but information frequently remained separated by departments or vendors. The second stage emphasized integration, with enterprise data warehouses, patient portals, standardized interfaces, mobile applications, and cross-department data exchange. The current stage increasingly emphasizes intelligence: data are not only stored and displayed but also used to predict demand, automate routine work, recommend actions, and dynamically coordinate resources.

This evolution changes the management logic of hospitals. Traditional operations management often relies on periodic reports and retrospective indicators. By contrast, smart operations seek to create a near-real-time view of hospital status. Bed occupancy, emergency department congestion, surgery schedules, staffing levels, laboratory turnaround times, discharge tasks, equipment location, and supply consumption can be integrated into dashboards or command platforms. Such visibility may allow managers to identify bottlenecks earlier and coordinate responses across departments. However, the introduction of a dashboard or command center should not automatically be equated with improved performance. A UK National Health Service evaluation found that a hospital command-center intervention did not produce consistent improvements in patient flow or data quality, illustrating that technology must be combined with process redesign and organizational engagement [4].

Accordingly, smart hospital operations should be regarded as a socio-technical system. Digital capability depends on technology, but outcomes also depend on governance structures, standardized workflows, workforce competence, leadership, incentives, and the quality of the underlying data. Digital transformation is therefore best understood as organizational transformation enabled by technology rather than as an information-technology project alone [3].

## **3. Core Technologies Enabling Smart Hospital Operations**

### *3.1. Electronic Health Records and Interoperable Data Platforms*

EHRs remain the central information foundation of smart hospitals. They aggregate diagnoses, orders, medications, laboratory results, imaging reports, procedures, and documentation that can be reused for clinical and managerial purposes. However, the

value of EHR data depends on interoperability. Hospitals frequently operate multiple systems developed at different times and by different vendors, leading to duplicated records, inconsistent definitions, and fragmented workflows. Interoperability therefore includes not only technical exchange but also consistent identification, terminology, data meaning, privacy rules, and organizational agreements [5].

Standards such as HL7 Fast Healthcare Interoperability Resources (FHIR) are increasingly important because they support structured exchange between heterogeneous systems. A 2024 systematic mapping review found continuing research on semantic interoperability, including terminology mapping, ontology-based approaches, natural language processing, and FHIR-based architectures [6]. For hospital managers, interoperability is a prerequisite for enterprise-level operational analytics. Without consistent data definitions and timestamps, indicators such as waiting time, bed turnover, length of stay, and discharge readiness may be unreliable even if they are displayed in sophisticated dashboards.

### *3.2. Artificial Intelligence and Advanced Analytics*

AI and machine learning are expanding from diagnosis into hospital operations. Predictive models can estimate admission probability, length of stay, surgical duration, patient deterioration, no-show risk, readmission, or resource demand. Prescriptive approaches can then combine predictions with optimization models to recommend schedules or allocations. In operating-room management, a systematic review found applications of machine learning in predicting surgical case duration, cancellations, and post-anesthesia resource needs [7]. These functions are relevant because operating rooms are high-cost environments in which small scheduling errors can create overtime, idle capacity, and downstream bed pressure.

The managerial value of AI is strongest when it reduces uncertainty in decisions that are repeated frequently and have measurable consequences. Examples include predicting tomorrow's bed demand, identifying patients likely to require intensive care, prioritizing discharge coordination, forecasting laboratory workload, and adjusting staffing to expected patient volume. Nevertheless, AI outputs should be considered decision support rather than automatic truth. Model performance can deteriorate when populations, clinical pathways, coding practices, or resource constraints change. Hospitals therefore require monitoring, human oversight, and procedures for recalibration and retirement of models [8,9].

### *3.3. Internet of Medical Things and Real-Time Sensing*

IoMT connects medical devices, wearables, sensors, location tags, and hospital assets to information systems. Its operational importance lies in making the physical hospital visible to digital management systems. Examples include real-time tracking of infusion pumps and wheelchairs, monitoring environmental conditions, detecting equipment utilization, tracking patient movement, and updating bed status. A systematic review of IoMT described smart hospitals as a major application domain and highlighted the role of connected devices in monitoring, data transmission, and integrated information platforms [10].

When combined with analytics, IoMT data can support preventive maintenance, reduce time spent locating equipment, improve asset utilization, and provide early warnings about abnormal conditions. However, increased connectivity also expands the cybersecurity attack surface. Device inventories, authentication, network segmentation, software updates, access control, and incident response therefore become management responsibilities rather than purely technical concerns.

### *3.4. Cloud Computing, Automation, and Robotic Process Automation*

Cloud and enterprise data platforms provide scalable storage and computing resources for analytics and AI. At the administrative level, robotic process automation (RPA) can automate rule-based tasks such as report generation, data transfer, appointment reminders, claims processing, medication-order tracking, and financial

counseling. A recent smart-hospital case report from Changi General Hospital in Singapore described the combined use of data analytics, AI, cloud infrastructure, IoMT, robotics, and RPA in a hospital-wide digital ecosystem [11]. The case also highlights an important management principle: digital transformation is more sustainable when data governance, AI governance, innovation structures, and workforce training develop alongside technical infrastructure.

Automation should not simply reproduce inefficient manual processes in digital form. Before automating a workflow, hospitals should identify unnecessary approvals, duplicate data entry, avoidable handoffs, and unclear responsibilities. Otherwise, digital tools may accelerate low-value processes rather than improve them.

### 3.5. Digital Twins and Simulation-Based Management

Digital twins are emerging as a more advanced layer of smart hospital management. A digital twin is a dynamic virtual representation of a physical entity, process, or system that can be updated using real-world data and used for monitoring, simulation, prediction, and optimization. In healthcare, digital twins have been studied at multiple levels, ranging from individual patients and organs to workflows and hospital systems [12-14].

For hospital operations, the most relevant possibility is to build virtual representations of patient flows, beds, staff, equipment, or facilities. Managers could test alternative staffing patterns, ward configurations, appointment policies, emergency surge scenarios, or discharge interventions before changing the real system. Current evidence indicates substantial potential but also important limitations related to data integration, model validity, computational complexity, privacy, and governance. Digital twins should therefore be viewed as an emerging management tool rather than a mature standard of practice (As shown in Table 1).

**Table 1.** Key Digital Technologies and Their Operational Management Roles in Smart Hospitals

| Technology                           | Representative applications                                                                                   | Management value                                                            | Main risks/limitations                                                 |
|--------------------------------------|---------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------------------------------------------------|
| EHR and interoperable data platforms | Integrated clinical and operational records; cross-department data exchange; longitudinal patient information | More reliable performance indicators; coordination; reduced duplicate entry | Poor data quality; incompatible standards; privacy and consent issues  |
| AI and predictive analytics          | Admission prediction; length-of-stay estimation; surgical scheduling; risk stratification; demand forecasting | Earlier decisions; improved capacity planning; reduction of uncertainty     | Bias; model drift; lack of explainability; overreliance on predictions |
| IoMT and real-time location systems  | Asset tracking; patient movement; equipment status; environmental monitoring                                  | Real-time visibility; equipment utilization; preventive maintenance         | Cybersecurity; device interoperability; maintenance burden             |
| Cloud platforms and data warehouses  | Scalable storage; enterprise analytics; cross-system integration                                              | Shared data foundation; faster analytics; easier scaling                    | Vendor dependence; access control; data residency and continuity risks |
| RPA and workflow automation          | Registration; reporting; data transfer; reminders;                                                            | Reduced repetitive work; fewer manual                                       | Automation of inefficient processes;                                   |

|                                |                                                                                         |                                                             |                                                                             |
|--------------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------|-----------------------------------------------------------------------------|
|                                | administrative processing                                                               | errors; faster processing                                   | exception handling problems                                                 |
| Command centers and dashboards | Bed capacity; emergency congestion; discharge tasks; staffing and throughput indicators | Shared situational awareness; cross-department coordination | Information overload; weak response protocols; benefits may be inconsistent |
| Digital twins                  | Simulation of patient flow, capacity, facilities, and operational scenarios             | Scenario testing; predictive and prescriptive planning      | Model validity; complex integration; high implementation requirements       |

4. Major Applications in Hospital Operations Management

4.1. Patient Flow, Bed Management, and Discharge Coordination

Patient flow is one of the most important operational challenges in hospitals because congestion in one area rapidly affects other departments. Emergency department crowding may be linked to delayed admissions, slow bed turnover, incomplete discharge preparation, transport delays, and limited post-acute capacity. Smart operations attempt to integrate these processes into a shared information environment. Real-time bed-management systems can display occupancy, expected discharges, cleaning status, isolation requirements, and patient placement needs. Predictive models can estimate incoming admissions or identify patients likely to remain hospitalized longer than expected.

The purpose is not simply to maximize occupancy. Very high occupancy can reduce resilience and increase delays when demand fluctuates. A more appropriate objective is to balance utilization with sufficient operational flexibility. Digital systems can help managers identify where capacity is constrained, but decisions still require clinical prioritization and coordination with nursing, housekeeping, transport, pharmacy, and discharge teams. Evidence from command-center implementations also cautions against assuming that visibility alone will resolve flow problems [4]. Effective patient-flow management requires clearly defined escalation pathways, accountability for delayed tasks, and continuous evaluation of whether interventions actually change waiting time, length of stay, and safety outcomes.

4.2. Operating-Room and Procedure Scheduling

Operating rooms represent a major source of hospital expenditure and revenue and are highly dependent on coordination among surgeons, anesthesiology, nursing, sterilization, beds, and diagnostic services. Inaccurate estimates of surgical duration can lead to cancellations, overtime, staff dissatisfaction, and underutilized capacity. AI-based duration prediction and cancellation-risk models may improve scheduling compared with simple historical averages, while optimization methods can support case sequencing and resource assignment [7].

For managers, the key is to connect prediction with operational rules. A highly accurate prediction has limited value if schedules cannot be adjusted or if incentives encourage departments to protect local capacity. Smart scheduling should therefore be combined with governance over block allocation, cancellation review, turnaround time, and post-anesthesia or inpatient-bed capacity.

4.3. Workforce Management and Administrative Burden

Workforce shortages make staff allocation a central management concern. Digital tools can forecast workload, support roster planning, match staffing to patient acuity, and automate repetitive administrative tasks. However, digital transformation can also create new workload. EHR systems may increase time spent on documentation, inbox management, and alert handling when interfaces are poorly designed. A 2024 systematic review and meta-analysis involving more than 66,000 healthcare professionals reported a substantial burden of EHR-related burnout and identified excessive time spent on EHR

tasks as an important risk factor [15]. Another systematic review similarly highlighted usability problems and time demands as major contributors to EHR-related stress in hospital clinicians [16].

This evidence has important implications for smart-hospital management. Digital efficiency should be evaluated from the user's perspective rather than measured only by the number of functions implemented. Time saved, clicks reduced, duplicate documentation eliminated, and interruptions avoided are meaningful management indicators. Hospitals should involve frontline staff in workflow design, conduct usability testing, and monitor whether digital tools redistribute work unfairly among professions.

#### *4.4. Medication, Laboratory, Equipment, and Supply-Chain Management*

Smart operations also extend to pharmacy, laboratories, equipment, and supply chains. Barcode systems, automated dispensing, electronic medication administration records, IoMT tracking, and RPA can improve traceability and reduce manual processing. In laboratories, automation can support specimen tracking, result reporting, and workload balancing. In equipment management, location technologies can reduce search time and support utilization analysis. Supply-chain systems can use historical demand, case mix, and seasonal patterns to forecast consumption and reduce both shortages and excessive inventory.

These applications illustrate the advantage of combining clinical and operational data. For example, supply demand is influenced not only by past consumption but also by scheduled procedures and expected admissions. An integrated data environment can therefore support more responsive procurement and inventory policies. Nevertheless, managers should avoid optimizing a single department at the expense of the entire patient pathway. Local efficiency indicators need to be linked to hospital-wide objectives.

#### *4.5. Quality, Safety, and Management Decision Support*

Quality management increasingly relies on automated surveillance and real-time indicators. Digital systems can identify overdue tasks, deterioration signals, medication risks, infection-control events, or deviations from clinical pathways. At the management level, dashboards can integrate quality, safety, efficiency, and financial indicators, helping leadership move from retrospective monthly reporting toward earlier intervention.

The main risk is indicator overload. When too many alerts and metrics are presented without prioritization, managers and clinicians may fail to distinguish urgent signals from routine variation. Effective smart management therefore requires a hierarchy of indicators, explicit thresholds, accountable owners, and clear action protocols. Data visualization should support decisions rather than merely display data.

### **5. Management Value of Smart Hospital Transformation**

The potential value of smart hospital operations can be organized into five dimensions. First, digital integration increases information transparency. Managers can obtain a more complete picture of hospital status rather than relying on delayed reports from separate departments. Second, predictive analytics can improve planning under uncertainty by estimating future demand instead of reacting only after congestion occurs. Third, automation can standardize routine processes and reduce avoidable manual work. Fourth, digital systems can strengthen coordination by making responsibilities, pending tasks, and resource constraints visible across organizational boundaries. Fifth, longitudinal data create a foundation for continuous quality improvement and evaluation.

These benefits are closely related to the concept of value-oriented management. A smart hospital should not be judged by how many AI systems, screens, robots, or sensors it owns. The relevant question is whether digital investment improves outcomes that matter to patients, staff, and the organization. Appropriate indicators may include waiting time, length of stay, cancellation rate, bed turnover, staff overtime, documentation burden, medication error rate, equipment utilization, patient experience, cost per episode, and avoidable readmission. Digital initiatives should have baseline measurements and predefined targets so that benefits can be evaluated after implementation.

At the same time, efficiency should not be pursued at the expense of safety or equity. An algorithm that reduces average waiting time but systematically disadvantages specific patient groups would not represent successful management. Balanced evaluation is therefore essential.

## **6. Challenges and Risks**

### *6.1. Data Fragmentation, Interoperability, and Data Quality*

Data fragmentation remains one of the most persistent barriers. Smart algorithms cannot compensate for missing, delayed, or inconsistently coded data. Interoperability reviews emphasize that successful exchange requires technical standards as well as organizational agreements, consent mechanisms, identity management, security, and common data definitions [5,6]. Hospital managers should therefore treat data quality as an operational asset with designated ownership, governance procedures, and audit mechanisms.

A common problem is that the same indicator is defined differently across departments. For example, "discharge time" may refer to the medical decision, completion of documentation, pharmacy completion, physical departure from the ward, or bed availability after cleaning. Without standardized definitions, cross-department dashboards may create false precision. Data governance must therefore precede advanced analytics.

### *6.2. Privacy, Cybersecurity, and AI Governance*

Smart hospitals create large, connected data environments that can improve care but also increase privacy and cybersecurity risks. Connected medical devices, cloud platforms, third-party AI services, and remote access expand the number of potential vulnerabilities. Cyber incidents can interrupt clinical services as well as expose sensitive information. Hospitals need enterprise-level cybersecurity governance, asset inventories, access control, backup and recovery procedures, staff training, and incident-response plans.

AI creates additional governance challenges. WHO guidance emphasizes human autonomy, safety, transparency, responsibility, inclusiveness, and sustainability in AI for health [8]. Its regulatory considerations also stress documentation, data quality, external validation, risk management, and collaboration among developers, regulators, healthcare professionals, and patients [9]. For hospital managers, governance should cover the complete AI lifecycle: problem definition, procurement or development, validation, implementation, monitoring, incident reporting, recalibration, and retirement.

### *6.3. Organizational Change and Workforce Acceptance*

Digital transformation often fails because of organizational rather than technical problems. New systems may alter professional roles, redistribute tasks, change decision authority, and challenge established routines. Resistance may occur when staff perceive that a system increases workload, reduces autonomy, or is introduced without adequate consultation. The EHR-burnout literature provides a clear warning that digitalization can generate unintended consequences when usability and workflow fit are neglected [15,16].

Change management should therefore include early stakeholder involvement, multidisciplinary governance, role-based training, protected learning time, feedback channels, and visible leadership support. Digital literacy is also becoming a management competency. Staff need not become data scientists, but they should understand the capabilities and limitations of algorithms, recognize data-quality problems, and know when human judgment must override automated recommendations.

### *6.4. Cost, Return on Investment, and Evidence Gaps*

Smart-hospital projects may require substantial expenditure on software, integration, infrastructure, cybersecurity, training, maintenance, and change management. The direct purchase price of a system therefore underestimates total cost. Managers should consider implementation cost, interface development, workflow disruption, staff time, upgrades, vendor support, and long-term dependence on external platforms.

Evidence of operational benefit is also uneven. Some technologies are supported mainly by proof-of-concept studies, single-center experiences, or retrospective evaluations. Even for widely promoted command centers, measurable effects may be inconsistent [4]. Hospitals should use staged implementation where possible, beginning with clearly defined problems and measurable outcomes. Pilot projects should include comparison periods or control units when feasible, and scaling decisions should be based on demonstrated value rather than technological enthusiasm.

## **7. Development Trends**

Several trends are likely to shape smart hospital operations over the next few years. First, hospitals will move from isolated applications toward enterprise-level platforms that combine EHR, operational, financial, device, and patient-generated data. Interoperability will become increasingly important as organizations attempt to reuse data across multiple AI and management applications.

Second, predictive analytics will increasingly be supplemented by prescriptive analytics. Instead of merely forecasting that congestion is likely, systems will recommend alternative staffing, bed allocation, scheduling, or discharge actions under specific constraints. The managerial challenge will shift from obtaining predictions to defining acceptable actions and accountability.

Third, multimodal and generative AI will influence administrative and knowledge work. Potential applications include documentation assistance, summarization, coding support, patient communication, and management reporting. These tools may reduce repetitive cognitive work, but they also require careful controls against hallucination, privacy leakage, automation bias, and unverified recommendations.

Fourth, ambient intelligence and IoMT will make data collection less dependent on manual entry. Sensors and context-aware systems may update equipment status, environmental conditions, and selected workflow events automatically. This could reduce documentation burden but will intensify requirements for cybersecurity and responsible surveillance.

Fifth, digital twins may develop from research prototypes toward operational simulation platforms. Reviews published in 2024 and 2025 indicate growing interest in applying digital twins to hospital management, workflow, facility design, and care coordination [12-14]. Their greatest management value may be the ability to test changes virtually before committing resources in the physical hospital.

Finally, governance will become a defining feature of mature smart hospitals. As AI systems proliferate, institutions will need formal structures for data stewardship, model oversight, technology assessment, cybersecurity, and digital ethics. The future smart hospital is therefore likely to be characterized as much by governance capability as by technological sophistication.

## **8. Implications for Hospital Managers**

For hospital administrators and medical management professionals, several practical principles follow from the literature. First, digital transformation should begin with an operational problem rather than a technology. Examples include excessive emergency waiting, delayed discharge, operating-room cancellations, or administrative burden. Second, every project should define measurable outcomes before implementation. Third, interoperable data and standardized definitions should be treated as foundational infrastructure rather than secondary technical details. Fourth, frontline staff should participate in workflow redesign and usability evaluation. Fifth, digital governance should integrate clinical leadership, nursing, operations, information technology, data science, finance, quality management, legal or compliance functions, and cybersecurity.

A useful evaluation framework is to assess each digital project across six dimensions: efficiency, quality and safety, patient experience, workforce experience, equity, and financial sustainability. This prevents a narrow focus on throughput or cost alone.

Hospitals should also monitor unintended consequences. If automation reduces clerical time but increases clinician review burden, or if predictive models improve average throughput while worsening access for vulnerable populations, the project requires redesign.

Digital maturity should therefore be viewed as the ability to repeatedly identify problems, integrate trustworthy data, implement appropriate technologies, redesign workflows, measure outcomes, and learn from results. This capability is more valuable than any single platform.

## 9. Conclusion

Digital transformation is reshaping hospital operations from fragmented, retrospective management toward integrated, real-time, and increasingly predictive systems. EHR interoperability, AI, IoMT, cloud infrastructure, automation, command platforms, and digital twins provide new tools for managing patient flow, beds, operating rooms, staff, equipment, supplies, quality, and administrative work. Nevertheless, the literature also shows that technology alone does not reliably improve hospital performance. Poor data quality, weak interoperability, inadequate workflow redesign, cybersecurity risks, AI governance gaps, user burden, and uncertain return on investment can limit or reverse expected benefits.

The central direction of smart hospital development should therefore be a shift from technology-centered construction to value-oriented digital operations. Hospitals need to combine interoperable infrastructure with strong governance, multidisciplinary leadership, workforce participation, and continuous evaluation. For medical management, the most important question is not whether a hospital uses advanced digital technologies, but whether those technologies help the organization provide safer, more efficient, more coordinated, and more sustainable care.

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